CROSSTALK MODEL FOR PAIR-SHIELDED DATA CABLES

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ABSTRACT

Due to the increasing demand for higher bandwidth the frequency and dynamic range covered by copper data cables is expanding. Generally well designed and produced cables using the technology of individually shielded pairs (S/STP) are capable to provide a positive attenuation-to-crosstalk-ratio (ACR) even for hundreds of MHz.

During the development phase from 100 MHz (Cat. 5, ISO 11801) /1/ to 600 MHz (Cat. 6, E DIN 44312/5) /2/ especially crosstalk performance has to be improved. The possibilities for improvements in attenuation for given impedance and conductor diameter are limited.

It is found that extremely length dependent effects are visible. Measurements show a length dependent crosstalk maximum which is above the specified limit at frequencies of about some 10 MHz when the length of the cable is 100 m or shorter. For different Cat. 5-cables it is found that for standard delivery length a crosstalk level of 80...90 dB up to 100 MHz is normal and the maximum only occurs when cutting down to shorter length (# 100 m).

Therefore the need for a special cable design appears to guarantee Cat. 6-performance for horizontal cables. Before defining design rules a mechanism explaining this effect is described. Computer simulations are compared with measurements to put some evidence in the model. It leads to a deeper understanding for an optimised cable design to avoid crosstalk problems, an essential aspect of future data cable design /3/.

Before the introduction of the crosstalk model the transfer impedance of the individual pair shield is described by the formulas known from literature. The impact of the transfer impedance values on the crosstalk of the S/STP-cables is discussed later.

TRANSFER IMPEDANCE OF SINGLE SHIELDED PAIRS

During the measurement of the transfer impedance of symmetrical cables the even-mode of a pair is considered and can be regarded as a coaxial cable. If the outer conductor of the coax is a metal foil of the width b wrapped around the insulated inner conductor with a radius r, the lay length l, the thickness d and the conductivity ?, the transfer impedance can be calculated as follows /4/

$$Z_k = R_0 \left(\frac{1}{\sin^2(a)} + \frac{\mathrm{j}\,\mathrm{r}\,\mathrm{d}}{d^2 \tan^2(a)} \right), \qquad (1)$$

with the DC-resistance

$$R_0 = \frac{\sqrt{l^2 + (2pr)^2}}{l\,b\,d\,k},$$

the angle

$$a = \arctan\left(\frac{l}{2pr} \right)$$

and the depth of penetration

$$d = \frac{1 + \mathrm{j}}{\sqrt{\mathrm{j} w\, m_0\, k}}.$$

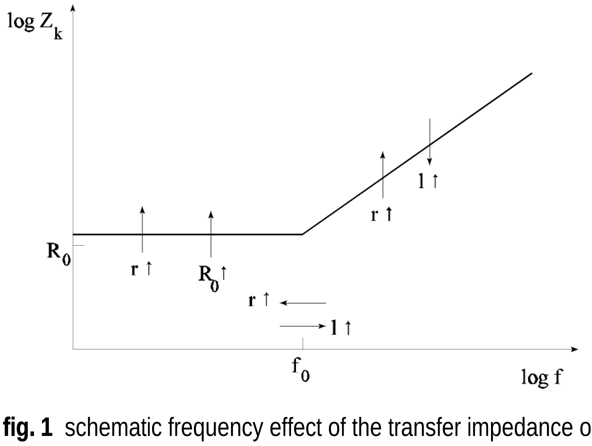

fig. 1 schematic frequency effect of the transfer impedance of a single shielded pair and influence direction of the main parameters

The transfer impedance of a single shielded pair of a standard Cat. 5 quality is up to a frequency of approximately 1 MHz constant. The value is a little bit higher than the DC-resistance. For frequencies higher than 1 MHz the transfer impedance is proportionally rising with the frequency. That is due to the inductivity of the wrapped metal foil. The influence of the variation of the main parameters on the transfer impedance of a single shielded pair is shown in fig. 1.

As the screening effect is high when the transfer impedance is low it is necessary to achieve a minimum relation between the values at the highest and lowest considered frequency. Fig. 1 and eq. (1) show different alternatives. Especially the diameter of the shield has high impact on transfer impedance, but also on other transmission parameters.

NEXT-MODEL FOR S/STP-CABLES

The near end crosstalk between two individually shielded pairs is caused by a multi step mechanism:

1) The interfering pair is fed at the near end with a signal in odd-mode. Due to non-ideal symmetry of the pair a part of this signal converts to even-mode. This results in a current in the shields.

2) The current causes an even-mode voltage in the interfered pair. The interference mechanism is described by the transfer impedance of the shielded pair; the transfer impedance is per definition the ratio of the even-mode voltage and the current in the shield.

3) Due to non-ideal symmetry of the interfered pair a part of the even-mode voltage converts to odd-mode and can be detected as crosstalk.

Besides the frequency effect of the transfer impedance the frequency dependent attenuation is important for the frequency effect of the crosstalk. Furthermore it is to be considered that the even-mode of a shielded pair is in most cases not terminated with the characteristic impedance of the even-mode waves.

The following simplifications are assumed for further modelling:

- The signal amplitude in even-mode and odd-mode are always connected by a constant value of the longitudinal conversion loss a_{LCL}. This is not dependent on the direction of conversion nor of the frequency.

- A current distribution in the shields of the pairs is not taken into consideration.

- The even-mode is not terminated; the magnitude of the reflection coefficient is 1.

- The superposition of partial waves is always constructive; the phases are disregarded.

- The attenuation in even-mode and odd-mode is the same.

- The transmission lines are homogeneous.

The following data are assumed (Cat. 5 S/STP cable):

- even-mode characteristic impedance:
  $Z_g = 30\,\Omega$
- velocity of propagation:
  $v = 0.8\,c_0$
- longitudinal conversion loss:
  $a_{LCL} = -40\ \mathrm{dB}$
- propagation constant:
  $$g = 2{,}4\,\frac{\mathrm{mNp}}{\mathrm{m}}\sqrt{\frac{\mathrm{f}}{\mathrm{MHz}}} + \mathrm{j}\frac{w}{\mathrm{v}}$$
- transfer impedance:
  $$Z_k = \begin{cases} 0.1\,\dfrac{\Omega}{\mathrm{m}}, & \mathrm{f} \le 1\mathrm{MHz} \\ 0.1 \cdot \mathrm{e}^{2{,}65\ \log\left(\frac{\mathrm{f}}{\mathrm{MHz}}\right)}\dfrac{\Omega}{\mathrm{m}}, & \mathrm{f} > 1\mathrm{MHz} \end{cases}$$

For the crosstalk sum four different signal paths of direct NEXT or caused by reflection are considered (fig.2):

1) A part of the transmitted signal in pair 1 converts to even-mode, influences pair 2 via near-end-crosstalk (NEXT), converts back to odd-mode and is received at A2. The NEXT between two coaxial elements is /4/:

$$a_n = 20\,\log\frac{Z_k}{4\,Z_g\,|\,g|}$$

For the first partial wave the attenuation sum is:

$$a_1 = 2\,a_{LCL} + a_n$$

2) Another partial wave converts to even-mode, propagates to E1, after a total reflection occurs at the open end E1 influences pair 2 via far-end-crosstalk, converts back to odd-mode and is received at A2.

3) Same like 2 but: first conversion to even-mode, far-end-crosstalk (FEXT) to E2, total reflection, propagation to A2 and conversion to odd-mode. For FEXT holds /4/:

$$a_f = 20 \log\left(\frac{Z_k\, l}{2\, Z_g}\right) - 20 \log(e) \operatorname{Re}(g)\, l$$

The attenuation sum for the paths 2) and 3) is identical:

$$a_{23} = 2\,a_{LCL} + a_f - 20 \log(e) \operatorname{Re}(g)\, l$$

4) Propagation to E1, conversion to even-mode, near-end-crosstalk to E2 and total reflection at E2 followed by propagation to A2 and conversion to odd-mode. The attenuation for this partial wave is:

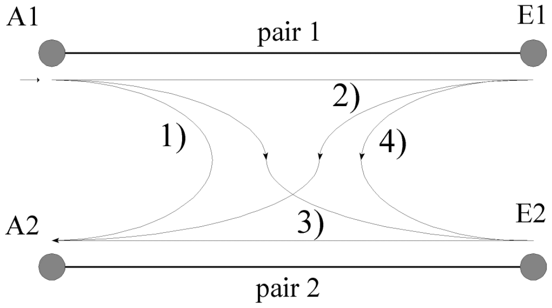

fig. 2 paths of crosstalk and reflection waves taken under consideration for crosstalk calculation

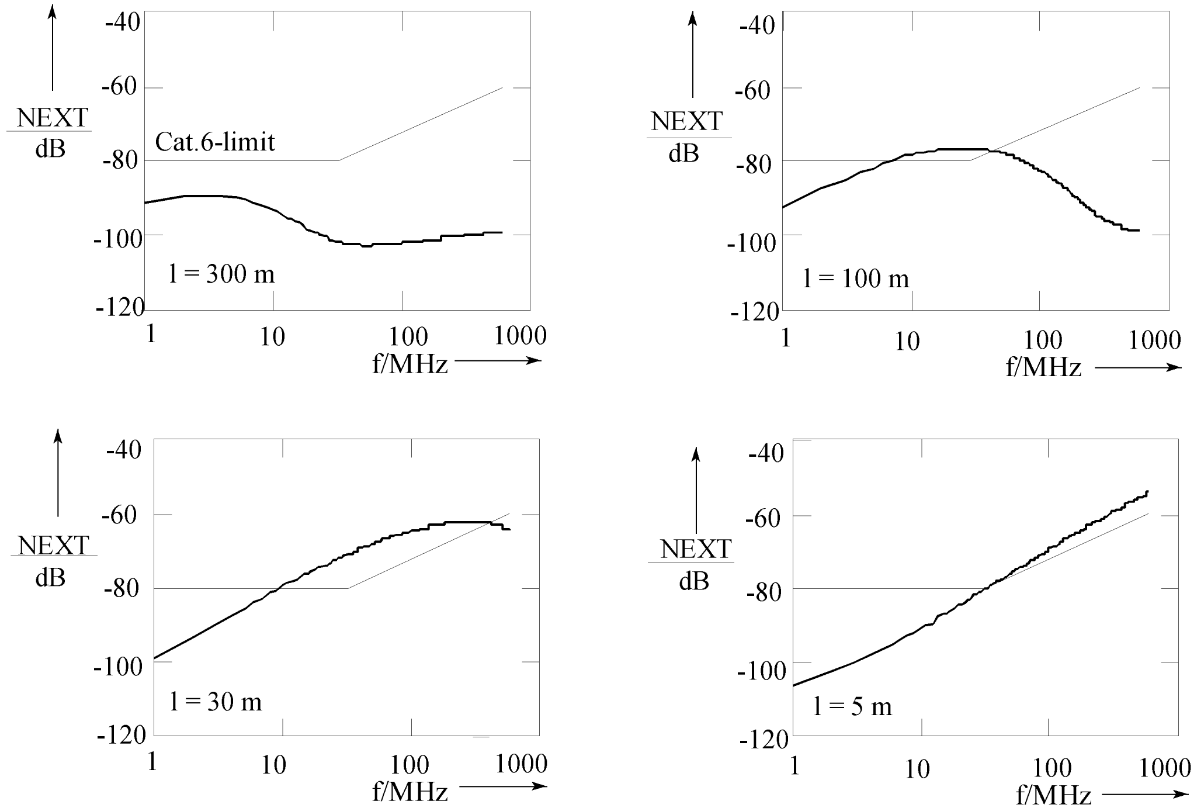

fig. 3 evaluation of the crosstalk model for various cable lengths

$$a_4 = a_n - 2\left(a_{LCL} - 20 \log(e) \operatorname{Re}(g) l\right)$$

The amplitudes of the partial wave are added and the resulting NEXT is:

$$a_{res} = 20 \log\left(10^{\left(\frac{a_1}{20}\right)} + 2 \bullet 10^{\left(\frac{a_{23}}{20}\right)} + 10^{\left(\frac{a_4}{20}\right)} \right) \quad (2)$$

The evaluation of eq. 2 for four different cable length is shown in fig. 3. Only for the length of 300m the calculated NEXT is below the specified limit. For the typical length of horizontal wiring (< 100 m) the crosstalk maximum is above the NEXT limit /2/. The frequency range for maximum value decreases with the cable length increasing. For longer cable length the characteristic maximum shifts towards lower frequencies reducing its maximum value at the same time.

The most important parameters are the longitudinal conversion loss (LCL) and the transfer impedance of the single shielded pair. A reduction of 1 dB in LCL leads to a reduction of 2 dB in NEXT. Also by improving the transfer impedance of the single shielded pair the maximum value of the NEXT maximum is reduced. So it is possible to meet the Cat. 6 requirements at a constant LCL level.

COMPARISON OF THE MODELS AND MEASUREMENTS

Fig. 4 presents the measured and calculated values of the transfer impedance for two variations of a single sreened pair. The foil of variation 1) has a shorter lay length and a smaller width compared to variation 2).

A helpful characteristic value is the ratio of the transfer impedance at 100 MHz and the DC-resistance of the pair shield. For a Cat. 6-type this ratio should be 10 times smaller than for a Cat. 5 typ.

Fig. 5 presents measurements of the near-end-crosstalk for different length of a Cat. 5 cable. The comparison with fig. 3 shows generally a good fit. Especially the position of the length dependant maximum shows a good correspondence.

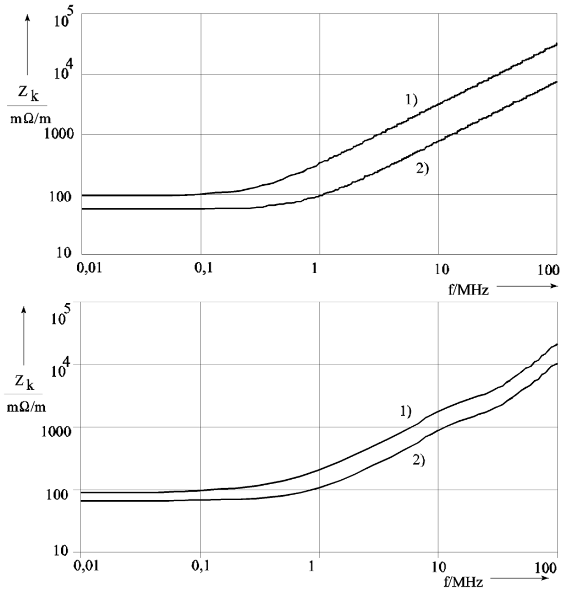

fig. 4 comparison of calculation and measurement of the transfer impedance of two types of single shielded pairs; 1) has shorter length of lay and smaller foil width than 2)

Nevertheless it can be seen from the measurement at longer length that further effects lead to a rising NEXT at higher frequencies. This can possibly be led back to direct coupling by electric or/and magnetic fields.

The measurement for short length shows effects of resonances. This is not taken into account in the presented model but indicates clearly the importance of the termination of even- and odd-mode waves.

CONCLUSION

The presented model enables an improved design of S/STP data cables. The model is based on a coupling theory that takes the conversion between odd-mode and even-mode, transfer impedance of the single shielded pair and the theory for far end and near end crosstalk of coaxial lines into account.

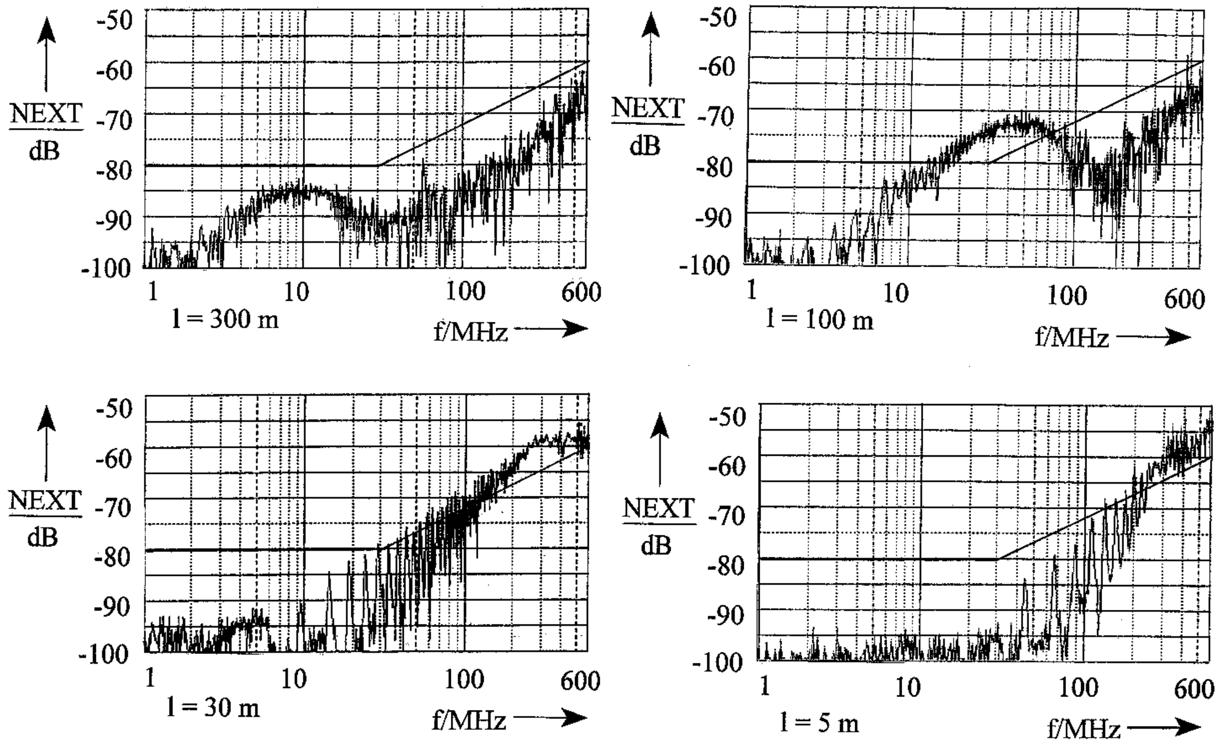

fig. 5 crosstalk measurement of a Cat. 5 S/STP-cable at various lengths

The crosstalk model also explains the unexpected differences of the measurement results between typical production and installation length. This leads to additional requirement for quality control and measurement to avoid that special problem.

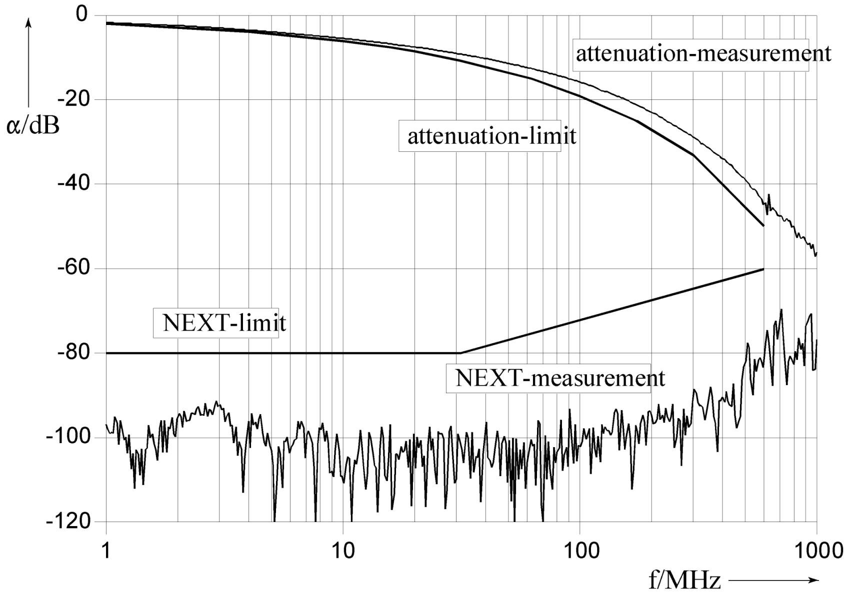

fig. 6 crosstalk and attenuation measurement of a high end Category 6 cable (UC600 SS22 4P, NK Networks); length of cut l = 90 m

Fig. 6 shows as a result a NEXT and attenuation measurement of a high end S/STP cable (100m). Positive crosstalk-to-attenuation-ratio (ACR) up to frequencies high above 600 MHz is achievable with respect to the mentioned design rules.

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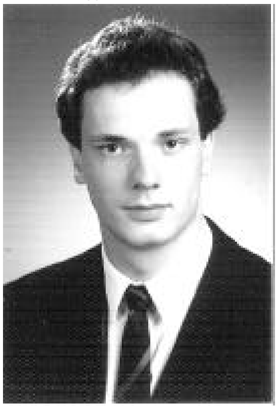
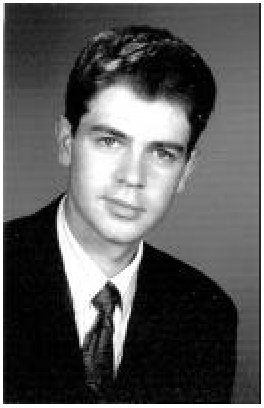


Christian Pfeiler received his diploma in electrical engineering in 1990 at the University of Dortmund. In 1995 he obtained a doctor's degree (Dr.-Ing.) at the same university. He joined the product developement department of NK Networks in 1995.



Andreas Waßmuth joined the company after his studies in electrical engineering at Ruhr Universität Bochum in 1986. After position in development and support for Local Area Networks he took over responsibility for the R&D-activities of copper telecommunication cables.